Chapel Hierarchical Locales

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Outline

- The problem: architecture and how to express it
  - The solution: *hierarchical locales*
  - Locality during compilation
  - Status and plans
Chapel’s Architecture Model Was So Simple

- Traditionally, Chapel supported only a 1D array of locales
  - Users could reshape/slice to suit their computation’s needs
  
- Apart from queries, no further visibility into locales

- Supports top level inter-node locality well
  - Assumes target compiler, runtime, OS, HW can handle intra-locale concerns
(HPC) architectures are varied and evolving rapidly
- Intra-node architecture becoming complex and important
- Hierarchy (example: NUMA)
- Heterogeneity (example: GPUs)

Performance requires using *all* architecture effectively
- But Chapel had no mechanism to refer to intra-node details

Need access to NUMA domains, CPUs, memories, etc.
What are the Requirements?

- Have just 3 architecture-dependent classes of operations:
  - Memory management (allocate, free, etc.)
  - Task support (initiate, move, etc.)
  - Communication
  - Helpful: do not need very many operations from each class

- Solution must be approachable, adaptable, flexible
  - Knowing Chapel + architecture and being motivated should be enough
    - Should not require “magic” and/or Chapel core team help
  - Must support experimentation and prototyping
Outline

✓ The problem: architecture and how to express it

➤ The solution: hierarchical locales

● Locality during compilation

● Status and plans
Solution: Chapel Hierarchical Locales

- Standardized class describes CPU+mem architecture
  
  ```
  class LocaleModel { ... }
  ```

- Composable, to reflect hierarchy

- Has required interface, referenced by generated code
  - Memory management
  - Task support
  - Communication operations
  - Hierarchical relatives (parents, siblings, children)

- May be implemented however desired
  - Typically in terms of other LocaleModel instances or runtime calls
Example: The Predefined numa Locale Model

```chpl
class NumaDomain : AbstractLocaleModel {
    const sid: chpl_sublocID_t;
}

// The node model
class LocaleModel : AbstractLocaleModel {
    const numSublocales: int;
    var childSpace: domain(1);
    var childLocales: [childSpace] NumaDomain;
}

// support for memory management
proc chpl_here_alloc(size: int, md: int(16)) { ... }

// support for "on" statements
proc chpl_executeOn
    (loc: chpl_localeID_t, // target locale
     fn: int,            // on-body func idx
     args: c_void_ptr,   // func args
     args_size: int(32)  // args size
    ) { ... }

// support for tasking stmts: begin, cobegin, coforall
proc chpl_taskListAddCoStmt
    (subloc_id: int,       // target subloc
     fn: int,             // body func idx
     args: c_void_ptr,    // func args
     ref tlist: _task_list, // task list
     tlist_node_id: int   // task list owner
    ) { ... }
```

$CHPL_HOME/modules/.../numa/LocaleModel.chpl

NUMA compute node

physical

conceptual

NUMA domain

mem

cpu cpu
cpu cpu
cpu cpu
cpu cpu

Figure 1. Conceptual and physical views of a compute node.

http://www1.pcmag.com/media/images/337192-intel-xeon-e5-chip.jpg?thumb=y
Where Predefined Locale Models Live

Chapel Source Code → Chapel-to-C Compiler → Generated C Code → Standard C Compiler & Linker → Chapel Executable

Chapel Compiler

Standard Modules (in Chapel)

Chapel-to-C Compiler

Runtime Support Library (in C)
- Tasks/Threads
- Communication
- Memory
- ...

Internal Modules (in Chapel)
Where Predefined Locale Models Live

- Locale models provided by Chapel are in internal modules.
- User specifies locale model as part of Chapel configuration when compiling application (via environment variable).
Hierarchical Locales Create a New Chapel Role

- Application programmer: work on applications
  - Express solutions in a natural way
  - Use forall statements to expose data parallelism
  - Use domain maps to inform Chapel about locality and affinity
Hierarchical Locales Create a New Chapel Role

- **Application programmer: work on applications**
  - Express solutions in a natural way
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- **Domain map specialist: work on locality**
  - In a general or conceptual way, not an architecture-specific one
Hierarchical Locales Create a New Chapel Role

- **Application programmer: work on applications**
  - Express solutions in a natural way
  - Use forall statements to expose data parallelism
  - Use domain maps to inform Chapel about locality and affinity

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- **Architecture modeler: work on architectural mappings**
  - Describe architectural hierarchy
  - Implement functional interfaces at various levels
Outline

✓ The problem: architecture and how to express it
✓ The solution: hierarchical locales
➢ Locality during compilation
● Status and plans
Context: Using Predefined numa Locale Model

$CHPL_HOME/modules/.../numa/LocaleModel.chpl

```chpl
class NumaDomain : AbstractLocaleModel {
    const sid: chpl_sublocID_t;
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// The node model
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     ref tlist: _task_list, // task list
     tlist_node_id: int // task list owner
    ) { ... }
```
The Application, as Architecture-free Code

// Stream Triad
config const m = 1000,
    alpha = 3.0;
const ProblemSpace = {1..m} dmapped Block(...);
var A, B, C: [ProblemSpace] real;
B = 2.0;
C = 3.0;
A = B + alpha * C;
The Application, as Architecture-free Code

Express parallelism abstractly, without referring to physical architecture

```plaintext
// Stream Triad
const m = 1000,
    alpha = 3.0;
const ProblemSpace = {1..m} dmapped Block(...);
var A, B, C: [ProblemSpace] real;
B = 2.0;
C = 3.0;
A = B + alpha * C;
```

\[ \alpha \cdot + = \]
The Application, as Architecture-free Code

Specify domain map in application code

Express parallelism abstractly, without referring to physical architecture

```c
// Stream Triad
config const m = 1000,
    alpha = 3.0;
const ProblemSpace = {1..m} dmapped Block(...);
var A, B, C: [ProblemSpace] real;
B = 2.0;
C = 3.0;
A = B + alpha * C;
```
Locality & Affinity in the Domain Map

// Block domain map
class Block: BaseDist {
    var targetLocDom: domain(rank);
    var targetLocales: [targetLocDom] locale;
    var dataParTasksPerLocale: int;
    var dataParIgnoreRunningTasks: bool;
    var dataParMinGranularity: int;
}

... iter these (param tag: iterKind,
    tasksPerLocale = dataParTasksPerLocale,
    ignoreRunning = dataParIgnoreRunningTasks,
    minIndicesPerTask = dataParMinGranularity)
{
    const numSublocs = here.GetChildCount();
    if locModelHasSublocs && numSublocs != 0 {
        ... _computeChunkStuff(min(numSublocs,
            here.maxTaskPar),
            ignoreRunning,
            minIndicesPerTask,
            ranges);

        ...}
}

Domain map:

- Describes distribution of indices (block, cyclic, etc.)
- Ties together locality, affinity, parallelism via iterators for forall-stmts
- Has a standardized interface, referenced by compiler-generated code
- Can interrogate locale model to learn about resources
- Is typically coded by a specialist
The Application, Translated by the Domain Map

```plaintext
const ProblemSpace = {1..m} dmapped Block(...);
var A, B, C: [ProblemSpace] real;
A = B + alpha * C;
```

```plaintext
coforall loc in targetLocales do on loc {
  coforall subloc in loc.getChildren() do on subloc {
    coforall tid in here.numCores {
      for (a,b,c) in zip(A,B,C) do a = b + alpha * c;
    }
  }
}
```
… Translated Again, by the Chapel Compiler

```
coforall loc in targetLocales do on loc {
    coforall subloc in loc.getChildren() do on subloc {
        coforall tid in here.numCores {
            for (a,b,c) in zip(A,B,C) do a = b + alpha * c;
        }
    }
}
```  

Chapel code

```
void main(...) {
    chpl_taskListAddCoStmt(fn_for_outer_coforall_stmt);
}

void fn_for_outer_coforall_stmt(...) {
    chpl_executeOn(loc, fn_for_on_stmt);
}

void fn_for_on_stmt(...) {
    chpl_taskListAddCoStmt(fn_for_middle_coforall_stmt);
}

void fn_for_middle_coforall_stmt(...) {
    chpl_taskListAddCoStmt(fn_for_inner_coforall_stmt);
}

void fn_for_inner_coforall_stmt(...) {
    for (...) { a[i] = b[i] + alpha * c[i]; }
}
```  

C code
Outline

✓ The problem: architecture and how to express it
✓ The solution: *hierarchical locales*
✓ Locality during compilation
   ➢ Status and plans
Today’s Locale Models: flat

- Direct replacement for the old compiler-implemented model
- Same performance as old compiler-based architecture support
- Default in all cases
Today’s Locale Models: numa

- **Functional**
  - Tasks follow memory affinity properly

- **Performance needs improvement**
  - Auto-init puts all mem on numa node 0
  - Working on memory locality
    - Auto-init improvements
    - Low-level memory management
  - Working on execution locality
    - Improving numa handling in Qthreads

- **Aiming at fall 2015 release**
Tomorrow’s Locale Models: “real” knc

- Current Chapel Intel Xeon Phi KNC support uses “flat”
- Duplicate and tune for KNC-specific properties (breadth, e.g.)
Tomorrow’s Locale Models: knl

- Intel Xeon Phi KNL would be an elaboration of numa
  - Similar to flat → knc

- Working on:
  - Access to high bandwidth memory
    - Additional sub-locale?
    - Specialized memory management
  - KNL-specific Qthreads improvements

- Aiming at spring 2016 release
Tomorrow’s Locale Models: accelerator

- Challenge: processor heterogeneity
Tomorrow’s Locale Models: numa+accelerator

- Challenge: hierarchy and heterogeneity
- Good composability test
Summary

- Hierarchical Locales feature helps “future proof” Chapel

- Enables separation of concerns
  - Application programmers are freed from architecture concerns
  - Domain map programmers are freed from architecture concerns
  - Compiler is freed from architecture concerns
  - Even the Chapel language is freed from architectural concerns

- Puts Chapel architectural policy in the hands of those most qualified to deal with it: architecture experts
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